

1. INTRODUCTION

Automotive Lightweighting Materials R&D

As a major component of the U.S. Department of Energy's (DOE's) Office of FreedomCAR and Vehicle Technologies Program (FCVT), Automotive Lightweighting Materials (ALM) focuses on the development and validation of advanced materials and manufacturing technologies to significantly reduce automotive vehicle body and chassis weight without compromising other attributes such as safety, performance, recyclability, and cost.

The specific goals of ALM are

1. By 2006, develop and validate advanced material technologies that will be needed to meet FCVT goals:
 - Enable significant reductions in the weight of body and chassis components and vehicle weight (50% reduction in weight of components and 40% reduction in vehicle weight relative to 1997 baseline five-passenger vehicle)
 - Exhibit performance, reliability, and safety characteristics comparable to those of conventional vehicle materials
 - Be cost-competitive, on a life-cycle basis, with costs of current materials
2. In support of the FreedomCAR goals, by 2010, develop and validate advanced material technologies that will
 - Enable reductions in the weight of body and chassis components by at least 60% and vehicle weight by 50% (relative to 1997 comparative vehicles)
 - Exhibit performance, reliability, safety, and recyclability characteristics comparable to those of conventional vehicle materials
 - Be cost-competitive, on a life-cycle basis, with costs of current materials

ALM is pursuing five areas of research: cost reduction, manufacturability, design data and test methodologies, joining, and recycling and repair. The single greatest barrier to use of lightweight materials is their high cost; therefore, priority is given to activities aimed at reducing costs through development of new materials, forming technologies, and manufacturing processes. Priority lightweighting materials include advanced high strength steels (AHSSs), aluminum, magnesium, titanium, and composites such as metal-matrix materials and glass- and carbon-fiber-reinforced thermosets and thermoplastics. The inclusion of AHSSs is an example that explains the use of the term "lightweighting," as opposed to just "lightweight," in order not to imply focus just on lower-density materials.

Collaboration and Cooperation

ALM collaborates and cooperates extensively in order to identify and select its research and development (R&D) activities and to leverage those activities with others. The primary interfaces have been and still are with the Big Three domestic automotive manufacturers, namely the FreedomCAR Materials Technical Team, the Automotive Composites Consortium (ACC), and the United States Automotive Materials Partnership (USAMP). This collaboration provides the means to determine critical needs, to identify technical barriers, and to select and prioritize projects. Other prominent partners include such organizations as the Aluminum Association, the American Iron and Steel Institute, the American Plastics Council, the Vehicle Recycling Partnership, the Society for the Advancement of Material and Process Engineering

(SAMPE), the International Magnesium Association, the International Titanium Association, and the Auto Parts Rebuilders Association. ALM also coordinates its R&D activities with entities of other U.S. and Canadian federal agencies. Interactions with the DOE Industrial Technologies Program (ITP), FCVT's High-Strength Weight Reduction (HSWR) Materials effort, and the Department of Natural Resources of Canada (NRCAN) are especially important by virtue of overlaps of interest in lightweight materials, and lightweighting

Project Selection and Stages

In cooperation with USAMP and the FreedomCAR Materials Technical Team, a procedure has been established to help facilitate the development of projects to help move high-risk leveraged research to targeted research projects that eventually migrate to the original equipment manufacturers (OEMs) as application engineering projects. Technology research projects are assigned to one of three phases: concept feasibility, technical feasibility, and demonstrated feasibility. Projects are guided to meet the requirements of each phase before they are allowed to move on to the next phase. The phases are defined as follows.

Concept Feasibility. Concept feasibility projects should contain a specific idea to address a need or to create something new. Projects are usually exploratory, small in monetary requirements, and short in duration. Projects should provide a yes/no answer to the value of the idea. All projects are required to have a detailed research plan, budget, and timing. These projects are typically less than \$200,000 and have a duration of 1–2 years. They can be ended before proceeding to technical feasibility if there is a lack of technical progress or if the preliminary business case turns out to be unfavorable. Successful concept feasibility projects can develop into technical feasibility projects.

Technical Feasibility. Technical feasibility projects should continue research development for ideas with proven merit or potential. These projects should identify the key barriers in implementing the technology and focus on overcoming them. Technical feasibility projects should have well-defined OEM/industry supplier participation and pull. They are usually larger, longer-term projects than concept feasibility projects, with research investment typically in the 1 to 2 million dollar range and a length of 2–3 years. Technical feasibility projects can be ended before proceeding to demonstrated feasibility if there is a failure to overcome the key barriers to implementation or if the cost or business case does not develop as favorably as initially assessed.

Demonstrated Feasibility. Technology projects that need larger-scale validation may become demonstrated feasibility projects. Not all technical feasibility projects will need a demonstration or validation program. These projects are few in number, are much larger in scale, and may involve component or system fabrication and testing. Support and leverage from the OEMs/industry is a key requirement for these projects.



Stage progression for project selection.

Once selected, R&D projects are pursued through a variety of mechanisms, including cooperative research and development agreements (CRADAs), cooperative agreements, university grants, R&D subcontracts, and directed research. This flexibility allows the program to select the most appropriate partners to perform critical tasks. ALM efforts are conducted in partnership with automobile manufacturers, materials suppliers, national laboratories, universities, and other nonprofit technology organizations. These interactions provide a direct route for implementing newly developed materials and technologies. Laboratories include Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL). PNNL manages the Northwest Alliance for Transportation Technologies, drawing on expertise and developments in the Northwest. ANL oversees recycling efforts, and ORNL provides overall technical management, including management for the DOE cooperative agreement with USAMP.

Research areas and responsible organizations	
Coordinated area	Organization
Production and fabrication of aluminum	The Aluminum Association, HSWR, ITP, Natural Resources of Canada (NRCAN)
Production and fabrication of magnesium	International Magnesium Association, NRCAN, HSWR
Recycling, reuse, repair of automotive parts and materials	Auto Parts Rebuilders Association, ITP, Vehicle Recycling Partnership, American Plastics Council
Fabrication of steel and cast iron	American Iron and Steel Institute, Auto/Steel Partnership, HSWR
Fundamental materials research	DOE Office of Energy Research, National Science Foundation
High-volume composite processing	Department of Commerce—National Institute of Standards and Technology's Advanced Technology Program
Materials research for defense applications	Department of Defense
Materials research for space applications	National Aeronautics and Space Administration
Crashworthiness	Department of Transportation
International vehicle material R&D	International Energy Association
Production and fabrication of titanium	International Titanium Association
Production and fabrication of composites	American Plastics Council

FY 2003 Accomplishments

Fiscal year (FY) 2003 was in the latter part of a second ALM phase that is running between about FY 2000 and FY 2004/5. In the first phase, between about FY 1994 and FY 2000, the ALM showed that

- Glass-fiber-reinforced polymer-matrix-composite (PMC) automotive structures could be manufactured at about the same cost as structures made of currently used steels, but they

could not meet the Partnership for a New Generation of Vehicles goal of 40% overall vehicle weight reduction.

- Acceptable automotive structures made of aluminum could achieve the Partnership for a New Generation of Vehicles weight reduction goal, but at a slight cost premium.

In its Ultralight Steel Autobody (ULSAB) program, which ran chronologically parallel to and independently of ALM's first phase, the steel industry showed that a body-in-white (BIW) could be produced using lower-strength HSSs that would be cost-neutral with (or cost even less than) current steels; but the BIW could not meet the PNGV weight reduction goal. The current second phase is focused on carbon-fiber-reinforced PMCs and magnesium and on manufacturing and recycling automotive components; some of the earlier efforts on aluminum and AHSSs are also being advanced. Some of the technologies developed by ALM and in the ULSAB are already on production vehicles and it is now apparent that aluminum, PMCs and the AHSSs are serious technical and economic contenders for eventually replacing some or all of the current steels when the market conditions are right.

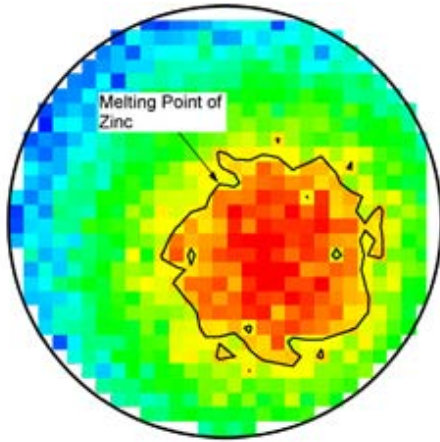
To meet the goals set forth for the program, ALM is developing materials and material processing technologies; validating these technologies through fabrication and evaluation of representative, nonproprietary test components; and developing adequate design data to facilitate their beneficial application. The research is balanced between nearer-term objectives and longer-term, higher-risk research. As the technical barriers are removed, the technology is made available to industry. Because of the broad area of research and the limited resources, projects have been selected to overcome the most significant barriers within the technical areas that the materials community considers higher-risk but that, if successfully developed, would result in significant progress toward ALM's goals.

During 2003, the Test Machine for Automotive Crashworthiness (TMAC) for Intermediate Rate Crush Studies was installed and dedicated at the National Transportation Research Center (NTRC) in Knoxville, TN. This unique machine will permit, for the first time, progressive crush experiments at high-strain-force levels and constant intermediate velocities. The data obtained from the tests are critical for the development of predictive crash models. In addition, outside users may gain access to the machine as part of the NTRC User Facility Program. Activities in this task will focus on working with users to execute small to moderate-size projects. It is expected that the user will supply specimens and fixturing and participate with ORNL in test execution. Because of its complex nature, operation of the machine will be restricted to specifically trained ORNL personnel.

Short welding electrode life is a barrier to the implementation of new lightweight materials, including galvanized steels and aluminum alloys, in automotive applications. ORNL, in collaboration with Edison Welding Institute and the Big Three automotive companies, has developed a model to predict the deterioration of



Metallic tubes tested in the TMAC demonstrate the conventional folding pattern associated with plastic hinge formation.



Schematic illustration of temperature distribution on the face of a copper resistance welding electrode. Regions in excess of the zinc melting point will experience accelerated degradation.

resistance-spot-welding electrodes through mechanical deformation and chemical attack. The model will allow industry to evaluate standard electrode materials, as well as new materials, under practical industrial conditions. The methodologies will lead to extended life of the existing electrodes and development of new long-life electrodes.

Significant advances were made in developing the technologies necessary to reduce the cost of carbon fiber to levels acceptable to industry, thereby enabling a cost-effective potential reduction in vehicle weight of 50%. Scientific development of the technologies to convert textile grade polyacrylonitrile (PAN) into carbon fiber was completed. This technology alone, if the engineering development phase is completed, can reduce the price of carbon fiber from \$7 per pound to below \$5 per pound. In addition, initial development of lignin-based precursors was concluded with a demonstration of a small composite made from carbon

fibers produced from lignin. The next phase will consist of scaling up the technology to tow-size fiber bundles. This technology has the potential to reduce the carbon fiber price to \$2.50–\$3.50 per pound.

The automotive industry depends heavily on resistance spot welds in the manufacture of vehicles. However, the most common methods for monitoring spot welding integrity in manufacturing operations are pry checks and physical teardown, during which spot welds are pried apart and visually inspected or measured with calipers. For several obvious reasons, these methods do not provide the necessary information in a timely, cost-effective fashion.

Lawrence Berkeley National Laboratory is working closely with automotive manufacturers to develop a nondestructive system that is sufficiently fast, accurate, robust, and cost-effective to be suitable for on-line inspection of spot welds in automotive components. Work to date demonstrates that characterization of spot welds is possible using ultrasonic phased-array technology. The advantages of the phased-array probes include the ability to perform high-resolution scans with increased detection capabilities, less sensitivity to probe placement, and the ability to inspect a wide array of welds with a single probe. The remaining research challenge is to refine the techniques so that they are suitable for large-scale manufacturing applications.

Significant progress was made in developing the technologies necessary to build a composite-intensive BIW. Initial molding trials were successfully completed for the inner and outer portions of the B-pillar portion of the design from the body side. This project addresses many challenging issues, including liquid molding of variable thickness sections (1.5–8.0 mm) at high volume fractions of reinforcing fibers. In addition to successfully molding several panels, researchers developed methods for joining the inner and outer sections of the panel. The bonded assemblies exhibited good dimensional control.



B-pillar test section, inner (left) and outer.

Future Direction

In FY 2002 and FY 2003, the Partnership for a New Generation of Vehicles was replaced by the FreedomCAR and Hydrogen Fuels Initiative, which has a 2012 goal of cost-neutral structures contributing to a fuel-cell-powered vehicle weighing 50% less than comparable vehicles of the mid-1990s. Thinking and planning on what will replace the current efforts in FY 2005 and beyond continues; but the process has already shown that a major role of lightweighting should be to reduce by as much as possible the required size of the fuel-cell propulsion system, which is expected to be heavier and more costly (at least initially) than the internal-combustion-engine propulsion system it replaces. Therefore, the focus of the second phase on materials with the greatest potential weight reductions turns out to be serendipitous for the third phase; thus technical-feasibility work is likely to continue along these lines. Base-technology, concept-feasibility, and demonstrated-feasibility work may also be considered.

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